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Appendix I – Charter

Mars Special Regions Science Analysis Group 2

(MEPAG SR-SAG2)

Assumptions

- Begin with the technical analysis of the MEPAG SR-SAG.
- The 2006 MEPAG SR-SAG [4] proposed that in order for a martian environment to be classified as non-special, it is necessary to be able to forecast that the relevant environmental conditions will not be exceeded for at least 500 years. For the purpose of this analysis, assume as a starting point that this 500-year figure does not need to be reconsidered. If review of the data suggests otherwise during the study, alternative time-periods may be considered.

Requested Tasks

1. Prepare updates in the following areas:
 - a. Reconsider information on the known physical limits to life on Earth, particularly experimental results and environmental observations, including (but not limited to) those:
 - i. At low water activity and low temperature, including adaptation to transient or periodic variability in both (via diurnal or annual cycling, etc.),
 - ii. Associated with biological capture and use of vapor-phase water,
 - iii. Relating to survival over very long time scales with extremely short growth periods.
 - b. Evaluate new (i.e., since 2006) observational data sets and new models from Mars that could be relevant to our understanding of the natural variations on Mars of water activity and temperature. Specifically consider at least:

- i. Recurring slope lineae (RSLs) discovered (and still actively being mapped) by MRO
 - ii. The physics of mixed-salt brines, including those resulting from the subsurface or condensation-mediated introduction of less-salty water
 - iii. Post-2006 thinking on the processes associated with the martian gullies (and especially those at mid-latitude).
 - iv. The possibility of subsurface methane and its potential significance as an indicator of temperature and water activity.
 - v. The discoveries from geomorphology, direct observation in recent craters, and by the MARSIS and SHARAD radars related to the distribution of surface and subsurface ice, and also any evidence that the radar investigations bring to bear on the presence or absence of deep martian liquid water.
 - vi. Atmosphere-regolith exchange processes and the non-steady-state effects of surface-atmosphere temperature differences and local (to micron-scale) availability of water or water vapor.
- c. Consider mineral and amorphous material water content and its potential biological availability, the observed and theoretical effects of mineral deliquescence, and its applicability to naturally occurring or spacecraft-induced Special Regions
- i. Consider the potential biological implications of the liquid formed by deliquescence
 - ii. Evaluate the observations made by Mars Phoenix in 2008 of relevance to this
 - iii. Evaluate the physical effects of deliquescence on transport processes related to microbial contamination.

- d. Reconsider the parameters used to define the term “special region;” propose updates to the threshold values for temperature and water activity, as needed; the minimum time-period (episodic or continuous) for the existence of a special region, especially if tied to a diurnal- or other short-period cyclic phenomenon; and the spatial scale at which criteria used to recognize “special” and “not special” regions should be applied. Mars is heterogeneous at many different scales, and our ability to develop practical distinctions depends on the scale at which the intent of the term “special” applies.
2. Prepare an updated description of the following in both text form, and as appropriate, in map form:
 - a. Mars environments that are judged to be “special”
 - b. Mars environments for which there is a significant (but still unknown) probability that the threshold conditions for a special region would be exceeded within the assumed 500-year limit. In the current policy, these are treated for planetary protection purposes as if they are special and the SAG should assume that this will be the case in any revised policy language.
3. To help guide future planning, prepare a preliminary analysis (e.g., <5 pages) of the kinds and amounts of water-related resources on Mars of potential interest to the eventual human exploration of Mars, and evaluate the planetary protection implications of attempting to access/exploit them. (A detailed analysis of this would require its own SAG, and this may be needed in the future).

Methods

- The SAG is asked to conduct its business primarily via telecons, e-mail, and/or web-based processes. One face-to-face meeting may be accommodated if needed.

- The Mars Program Office at JPL will provide logistical support, including travel funding for US MEPAG participants.

Timing, Schedule

- The SAG is expected to begin its discussions by Nov. 15, 2013.
- A preliminary status report (PPT format) to the MEPAG Chair, to Mars Exploration Program Science personnel, and to COSPAR sponsors is requested by Feb. 1, 2014.
- A substantial PPT-formatted status report that touches on all technical areas mentioned in the charter is required by Mar. 15, 2014 (note the Lunar and Planetary Science Conference is Mar. 17-21, so this could be a good opportunity for a briefing). This report will be used as an input to the COSPAR process, below.
- Receive comments back from COSPAR workshop the week of Apr. 14th.
- Final draft PPT-formatted report for presentation at the next MEPAG meeting (tentatively proposed for the week of May 12, 2014). It is expected that 1) this report will be made available for electronic comment by the community; and 2) its proposed findings will be reviewed and discussed at the meeting.
- The final text report (and PPT-formatted version), due NLT Jul. 15, 2014, is expected to address and resolve points raised in review.

Lisa Pratt, MEPAG Chair

Michael Meyer, NASA Lead Program Scientist for Mars Exploration, NASA HQ

Rich Zurek, Mars Program Chief Scientist, JPL

David Beaty, Chief Scientist, Mars Exploration Directorate, JPL

October 10, 2013

Appendix II – Science Analysis Group Committee Members

[Table Appendix 2, here]

Figure Legends:

FIG. 1. Conceptual diagram showing areas of interest when considering the growth and reproduction of terrestrial microbes on Mars.

FIG. 2. Prediction of the orbit of Mars based on an integration of solar system dynamics (Laskar *et al.*, 2004). The vertical dashed line marks 500 years from now. Each element increased slightly: eccentricity by 0.00054, obliquity by 0.062°, and L_S of perihelion by 3.24° above present day values of 0.0933, 25.189° and 251.05°, respectively.

FIG. 3. Annual mean temperature for current orbit (solid) and for 500 yrs in the future (dashed). Differences are barely visible. The result is based on a numerical thermal model (Mellon and Jakosky 1992; Mellon *et al.*, 2004) assuming a surface thermal inertia of $250 \text{ J m}^{-2} \text{ K}^{-1} \text{ s}^{1/2}$ and albedo of 0.25.

FIG. 4. Trend in annual mean temperature between the current epoch and 500 years in the future, from Fig. 3. Northern latitudes are warming, while southern latitudes are cooling. Both polar regions are warming.

FIG. 5. Conceptual illustration of the energetic coupling in biological metabolism, where electrons from fuels (including various inorganic compounds) are transferred to oxidants with the generation of metabolic energy. Only reactions with a negative free energy change (ΔG) are energetically feasible. Modified and reprinted from Nealson and Stahl, 1997, with permission from the Mineralogical Society of America.

FIG. 6. Temperature limits of cell division and other metabolic activity in terrestrial microbes as described in references listed in Table 2.

FIG. 7. The limits of microbial survival relative to water activity (a_w) as currently represented in the literature.

FIG. 8. Ranges of water activity that permit microbial respiration (CO_2 production) in soils affected by matric effects (varying degrees of desiccation); ranges for microbial cell reproduction are presumably more restrictive (left side of figure). Ranges of solute (salt or sucrose)-induced water activity that permits microbial cell reproduction (right side of figure).

FIG. 9. Relationship between water film thickness and water potential in porous media. Modeled values (lines) and measures (points) vary with the nature of the porous medium, but decline sharply as water is lost from the system between $a_w = 0$ (saturation) and $a_w = 0.9$, at which point the average water film thickness is < 15 nm. Modified from Tokunaga, 2012. Reprinted by permission of John Wiley & Sons, Inc.

FIG. 10. A phase diagram for water, showing the interaction between temperature and pressure on the form in which water is found. Note that the surface pressure and temperature on Mars are both often in ranges that allow water to exist as a liquid on the surface (Mogk, 2014).

FIG. 11. A diagrammatic cross section through a smectite clay mineral. Modified from Johnson, 2010. Reproduced with permission of Mineralogical Society of Great Britain and Ireland.

FIG. 12. Air and rock humidity data collected from sandstones in the Linnaeus Terrace, McMurdo Dry Valleys (Friedmann *et al.*, 1987). Fluctuations in humidity are greater in the air (solid line) than in rock samples (dotted line). Overall, average humidity measured in rock samples is higher than that of the air. Reprinted by permission of Springer.

FIG. 13. MRO HiRISE image of RSL in Melas Chasma, Valles Marineris (McEwen *et al.*, 2014a). Arrows point out tops and bottoms of a few lineae. Portion of HiRISE image ESP_031059_1685. Image credit: NASA/JPL/University of Arizona.

FIG. 14. Global map of fully and partially confirmed RSL sites documented by end of 2013. Simple cylindrical map projection.

FIG. 15. Martian gullies exhibiting erosional alcoves, channels, and depositional aprons. Left panel: mid-latitude gully at 37.46°S, 222.95°E; north is up (HiRISE ESP_033290_1420). Right panel: equatorial gully at 8.41°S, 313.31°E; north is to the left (HiRISE ESP_018518_1715). Scale of each panel is ~1 km from top to bottom. Image credit: NASA/JPL/University of Arizona.

FIG. 16. Global distribution of gullied landforms. Colored data points (Harrison *et al.*, 2014; <http://www.hou.usra.edu/meetings/lpsc2014/pdf/2124>) indicate dominant gully orientation; blue = pole-facing, yellow = east/west facing, red = equator-facing, and purple = no preference. Similar maps have previously been produced by several other authors. Black data points from another study (Auld and Dixon, 2014; <http://www.hou.usra.edu/meetings/lpsc2014/pdf/1270.pdf>) of 866 gully-like landforms mapped based on images from the first 25,000 orbits of the HiRISE camera, including equatorial sites. Mapping criteria did not include age, so these gullies are not necessarily all active in the modern time, or even young.

FIG. 17. Map of active gullies (excluding small alcove-fan features in north polar sand dunes) and other monitoring sites. The majority are located in the southern hemisphere where long winters result in thicker seasonal CO₂ deposits. Reprinted from Dundas *et al.*, 2014b, with permission from Elsevier.

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FIG. 18. Possible relationships between gullies and ice. a) Many gullies may have been carved, at least in part, by wet flows sourced from the melting of ancient ice. b-c) Only the subset of these gullies that retain ice today represent potential Special Regions.

FIG. 19. Fans and gullies from water action in 58.5 km diameter Mojave Crater (HiRISE image PSP_001415_1875). Image credit: NASA/JPL/University of Arizona.

FIG. 20. Models of the lifetime of hydrothermal systems as a function of crater diameter: A&K = Abramov and Kring, 2005; R&S = Rathbun and Squyres, 2002; B *et al.* = Barnhart *et al.*,

2010, and N et al. = Newsom *et al.*, 2001. Also shown are three large young craters: Tooting, Mojave, and Hale.

FIG. 21. Athabasca Valles streamlined islands at 9.4°N, 156.3°E. HiRISE image

PSP_011825_1895. Image credit: NASA/JPL/University of Arizona.

FIG. 22. Slope streaks on a dust-mantled slope. Image shows a portion of the illuminated wall and floor of a trough in the Acheron Fossae region of Mars (37.32°N, 229.11°E). From HiRISE PSP_001656_2175. Image credit: NASA/JPL/University of Arizona.

FIG. 23. Dark dune streaks at 83.5°N, 118.6°E. Imaged at Ls=55.7. Black arrow points to a small cloud of dust and slope streaks kicked up by sand and ice cascading down the dune slope (Hansen *et al.*, 2013).

FIG. 24. Collapsed pits associated with extensional tectonics, northeast of Arsia Mons at -2.27°S, 241.90°E (Cushing, 2012). HiRISE image ESP_014380_1775. Image credit: NASA/JPL/University of Arizona.

FIG. 25. Ground temperatures as a function of depth and season. Each curve is a diurnal average at 25 day intervals throughout the Mars year. a) shows the temperature profiles assuming a homogenous ice-free soil, while b) shows the same assuming ice saturated pore space below 50 cm. The presence of the high thermal inertia ice has a substantial cooling effect. Modified and reprinted from Mellon *et al.*, 2004, with permission from Elsevier.

FIG. 26. Conceptual illustration of shallow subsurface conditions at the Phoenix landing site.

Note that cold temperatures (below 200K/-73C) are present whenever the relative humidity is above 60%, while summer temperatures of greater than 255K are associated with relative humidities well below 10%.

FIG. 27. Stability diagram for the $\text{Ca}(\text{ClO}_4)_2$ -water system overlaid with diurnal Martian temperature and relative humidity data from several different missions (Gómez-Elvira *et al.*, 2012; Rivera-Valentin and Chevrier, 2014; Savijarvi, 1995). Comparison with the $\text{Ca}(\text{ClO}_4)_2$ stability diagram indicates the occasional formation of a liquid phase, although the brine formed does not qualify as a Special Region due to the low temperature and water activity.

FIG. 28. Depicts the eutectic temperature (i.e., maximum freezing point depression) of several Mars-relevant salts (y-axis), and water activity*100 (RH/100) of the salts at their eutectic point (x-axis). It can be seen here that calcium perchlorate has the lowest T_E of many salts found on Mars.

FIG. 29. Cloud and snowfall observed by Phoenix LIDAR on Sol 109. Snow deposits could generate localized accumulations through drift. From Whiteway, *et al.*, 2009. Reprinted with permission from AAAS.

FIG. 30. Failure modes during EDL that could cause a non-nominal landing and possibly create localized Special Regions—particularly those occurring after parachute failure, where the

general purpose heat source modules could end up being buried with spacecraft components adjacent to subsurface ice.

FIG. 31. Schematic diagram of the Special Region (“wet layer”) that could be created by an RTG or its radioisotope heat source in the vicinity of ice-laden surface material.

FIG. 32. A fully buried radioisotope heat source (General Purpose Heat Source = GPHS) can melt ice above and below it’s location, leading to possible pooling and persistence of water nearby.

FIG. 33. Olympus Mons and the Tharsis volcanoes, showing (in yellow) areas where glacial deposits would have formed, and where residual ice may still be found under meters’ thick sublimation-lag deposits. Excerpt from Tanaka *et al.*:
http://pubs.usgs.gov/sim/3292/pdf/sim3292_map.pdf (accessed 8/28/2014).

FIG. 34. a) Detecting Buried Ice: Bowl-shaped crater and Ring-Mold Crater (RMC) on Lineated Valley Fill (LVF); **b)** Cross section showing interpreted relations to buried ice (Kress and Head, 2008). Reprinted with permission of John Wiley & Sons, Inc.

FIG. 35. Distribution of identified sites of lineated valley fill, lobate debris aprons, and concentric crater fill on Mars. Reprinted from Dickson *et al.*, 2012, with permission from Elsevier.

FIG. 36. Fresh impact crater site exposing bright materials. Crater is 8 m in diameter and located at 55.58°N, 150.6°E. The crater formed sometime in the time period between Jan. 26, 2008 and Sept. 18, 2008. HiRISE image PSP_010625_2360. Image credit: NASA/JPL/University of Arizona.

FIG. 37. Maps showing the distribution of ice-exposing (white) and non-icy (black) new impacts (Dundas *et al.*, 2014a). Background of top map is Thermal Emission Spectrometer dust cover (warmer colors = higher dust content). Background of bottom map is water equivalent hydrogen (warmer colors = lower hydrogen and thus water content). Reprinted with permission from John Wiley & Sons, Inc.

FIG. 38. Example of polygonal patterned ground. These patterns form from subsurface seasonal thermal-contraction fractures within permanently-frozen ice-rich permafrost. Fractures gradually consume loose surface soils creating an observable honeycomb-like network of shallow troughs. Subframe of HiRISE image PSP_005761_1145 at 65.305°S, 136.562°E. Image credit: NASA/JPL/University of Arizona.

FIG. 39. Near surface ground ice uncovered at Phoenix landing site. The image shows the 22 cm wide, 35 cm long, and ~7-8 cm deep "Dodo-Goldilocks" trench after two digs by Phoenix Robotic Arm. Image credit: NASA/JPL-Caltech/University of Arizona/Texas A&M University.

FIG. 40. Summary map outlining areas of non-polar subsurface ice detections based on data from the MARSIS and SHARAD instruments (J. Plaut, personal communication, 2014).

FIG. 41. Ice detection by the SHARAD instrument (on the MRO spacecraft), showing the discontinuous nature of thick subsurface ice in the middle latitudes (Plaut *et al.*, 2010).

FIG. 42. Images from the Surface Stereo Imager (SSI) of the Phoenix robotic arm deployed showing show the Robotic Arm Camera (RAC), Thermal and Electrical Conductivity Probe (TECP), and the rasp on the bottom of the scoop (Arvidson *et al.*, 2009). Insert is another pose showing the front of the scoop with the titanium blade and divot point for close-up imaging of soil with the RAC. Right-hand view shows the bottom of the scoop with the tungsten carbide scraper blade. Reprinted by permission of John Wiley & Sons, Inc.

FIG. 43. Temporal changes to Soil in the Phoenix Scoop after sample acquisition (Arvidson *et al.*, 2009). Phoenix Robotic Arm Camera images showing temporal changes to soil in the scoop. (a and c) Attempted (sol 60) and (b and d) actual (sol 62) delivery of icy soil from Snow White to the Thermal and Evolved Gas Analyzer oven 0 screen. Not enough material was delivered on sol 62 so a sublimation lag was scooped up and successfully delivered and received by TEGA oven 0 on sol 64. Reprinted by permission of John Wiley & Sons, Inc.

FIG. 44. The Phoenix lander struts showed spherules that appeared, darkened and disappeared with time (Renno *et al.*, 2009). The images below show a closer view of the strut area noted in the top image. Reprinted by permission of John Wiley & Sons, Inc.

FIG. 45. Distribution of phyllosilicates, chlorides, carbonates, and sulfates on Mars, as determined from orbiting missions (Ehlmann and Edwards, 2014). Reprinted by permission of Annual Reviews.

FIG. 46. Map of features of relevance to interpreting Special Regions on Mars. Units indicate depth and spatial continuity of shallow ground ice or potential transient surface water (see Section 7.3.1). Map base is Mars Orbiter Laser Altimeter digital elevation model of Mars (~463 m/pixel; Neumann *et al.*, 2001) in Simple Cylindrical projection. Map unit boundaries are drawn using geographic information system (GIS) software.

FIG. 47. Locations of Recurrent Slope Linea (RSL) on Mars identified at the time of this publication. RSL require high-resolution and time-series observations for their identification, and may comprise the most significant candidate sites for characterization as Mars Special Regions.